U.S. Naval Air Development Center

Johnsville, Pennsylvania

NADC-MR-6620 21 October 1966

Silicone Submersion - A Feasibility Study

Naval Air Systems Command
Air Task A34531 059 R02201 03
Problem Assignment J04AE13-7

Bureau of Medicine & Surgery
Work Unit MF 022.03.02.7002 Report No. 9

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Limitations concerning the distribution of this report and revelation of its contents appear on the inside of this cover.

DEPARTMENT OF THE NAVY
U. S. NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE
WARMINSTER, PA. 18974

Aerospace Medical Research Department

NADC-MR-6620 21 October 1966

Silicone Submersion - A Feasibility Study

Naval Air Systems Command
Air Task A34531 059 R02201 03
Problem Assignment J04AE13-7

Bureau of Medicine & Surgery
Work Unit MF 022.03.02.7002 Report No. 9

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Prepared by: Paul Webb, M.D.
James F. Annis
Webb Associates, Inc.
Yellow Springs, Ohio.

Randall M. Chambers
Contract Monitor: Randall M. Chambers
Contract N62269-3212

Carl F. Schmidt
Approved by: Carl F. Schmidt, M.D.
Research Director
Aerospace Medical Research Department

Released by: E. M. Wurzel, CAPT, MC, USN
Director
Aerospace Medical Research Department

SUMMARY

This report details a study which demonstrated the feasibility of maintaining men totally and continuously submerged for five days by using silicone fluid in a specially designed tank. Five submersions were tried, 3 were in water for 6 hours for training purposes and 2 were in silicone; one for 16 hours and the final run which lasted a full five days (120 hours) with complete submersion for about 60% of the time and head out immersion for the remaining 40%. It was found that silicone fluid can be used as a weightless simulation medium in prolonged immersion and that subjects can be kept free of skin irritation or maceration for long periods of time if dilligent quality control of the fluid is maintained. It was also found that long submersion need not result in a negative water balance due to diuresis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SILICONE SUBMERSION — a feasibility study

INTRODUCTION

This report concerns a study which demonstrated the feasibility of maintaining men totally and continuously submerged for five days by using silicone fluid in a specially designed tank.

In experiments involving total submersion in water, there are a variety of problems which place severe constraints on the duration of continuous submersion. These problems include the following, in roughly descending order of improtance:

1. maceration of the skin;
2. disposition of body waste without leaving the bath;
3. inability to separate body aqueous secretions and excretions from the water.

We circumvented these problems by using a silicone fluid for the submersion bath. This liquid is of extremely low toxicity, does not mix with water, and is suitable for use in a bath to produce neutral bouyancy.

The reasons for establishing the feasibility of prolonged submersion are numerous, including the following basic ones:

a. The technique could be used to support men who are to be kept neutrally bouyant for days and weeks while occupying a workplace and living layout similar to those being studied for space stations and undersea devices.

b. Prolonged neutral bouyancy simulates important aspects of the weightless state, and can be used to study changes in circulation and muscle tone, demineralization of bone, and other physiological problems.

c. The technique may prove valuable in analysis of collected body waste, and in studies in thermal physiology.

Certain silicone fluids, especially the dimethylpolysiloxanes (Dow Corning 360 Medical Fluid, General Electric SF-96, Union Carbide L-45) have been extensivley used in skin creams and cosmetics; as volume filling liquid under the skin, in muscle, and in the eyeball; as liquid carriers for preparations to be drunk; as an inhalant vehicle in aerosal sprays; and to coat and soothe mucous membranes in various parts of the body. The material is of phenomenally low toxicity and is biologically inert in most applications (Rowe, et al, 1948). Extensive animal studies have demonstrated the inertness of this type of silicone when administered by any route. The only reported problem is irritation of the surface of the eye, which is suspected to be from interference with normal lacrimal irrigation.

In contrast to water submersion, where hydration of the skin, maceration, and bacterial infection are limiting problems, silicone submersion promises an unusual freedom from maceration and infection, provided that:

a. the skin is kept scrubbed, and is flushed with clean silicone fluid;

b. skin debris, fat, sebum, and bacteria are thoroughly filtered and separated from the silicone fluid;

c. water content of the fluid maintained below 100 ppm.

The recent use of dimethylpolysiloxane as a partial immersion bath for treatment of patients with extensive burns, (Gerow, et al, 1963) (Gerow and Weeder, 1964) where large areas of skin are denuded, has produced no toxicological response. No harmful effects were observed in control studies done on a normal male subject who was immersed to the neck for about 23 hours a day for 14 days.

From this experience it was felt safe to proceed to a trial of total submersion in silicone fluid, with no periods of removal from the bath. The goal was to achieve 120 hours (5 days) of continuous submersion.

Five submersions were completed. The first three were in water, lasted 6 hours, and were used for training of the three available subjects and also of the experimental team. The fourth submersion was in silicone fluid with subject B, and lasted 16 hours. It served as a useful test of apparatus and procedures, which led to improvements particularly in the breathing system which had caused early termination from discomfort. The final run with subject C lasted the full 5 days, or 120 hours, with complete submersion for about 60% of the time, and head-out immersion the remaining 40% of the time.

SUBMERSION FACILITY

The subjects were contained in a large flexible bag of clear vinyl (0.020") filled with approximately 66% of the 150 gallons of circulating silicone fluid. The bag was suspended in water contained in a wooden immersion tank eight feet long, four feet wide and five feet deep. The vinyl bag was open along the top to provide complete access to the subject. The sides of the bag along the open top seam folded over a wooden support framework above the surface of the water. The submersion bag was large enough to allow full extension of the legs and nearly complete abduction of the arms. The flexibility of the bag also permitted the subject to move the sides or bottom of the bag to conform to any position change desired. Generally the subjects lay horizontally and completely submerged within the silicone fluid even though variations in position were needed for subject comfort and the performance of various functions. A large window in one side of the wooden tank permitted good visual contact in both directions. This feature reduced the isolated feeling of the submerged subject and afforded the experimenters continuous visualization of the subject. For the physical arrangement of the system see Figure 1.

The filtration equipment contained three filter units built by the Baker Filtration Company of El Monte, California. The main filters for processing the silicone oil used diatomaceous earth as the primary filtering agent. Activated charcoal and Drierite were also used. The diatomaceous earth removed particulate matter, water, and the larger bacteria. The charcoal removed oils, organic acids and other contaminants. Drierite helped in water removal. Two filter units were mounted together and interconnected. Each consisted of 1 1/2 horsepower pump, slurry tank, filter bed, and valves with a common inlet and outlet and appropriate piping to permit, besides running singly or together, use of either pump with either or both filter beds. This flexibility gave freedom to change pumps or filters and still allow continuous filtration. A diagram of this arrangement is shown in Figure 2.

Figure 1. General arrangement of submersion facility - end view.

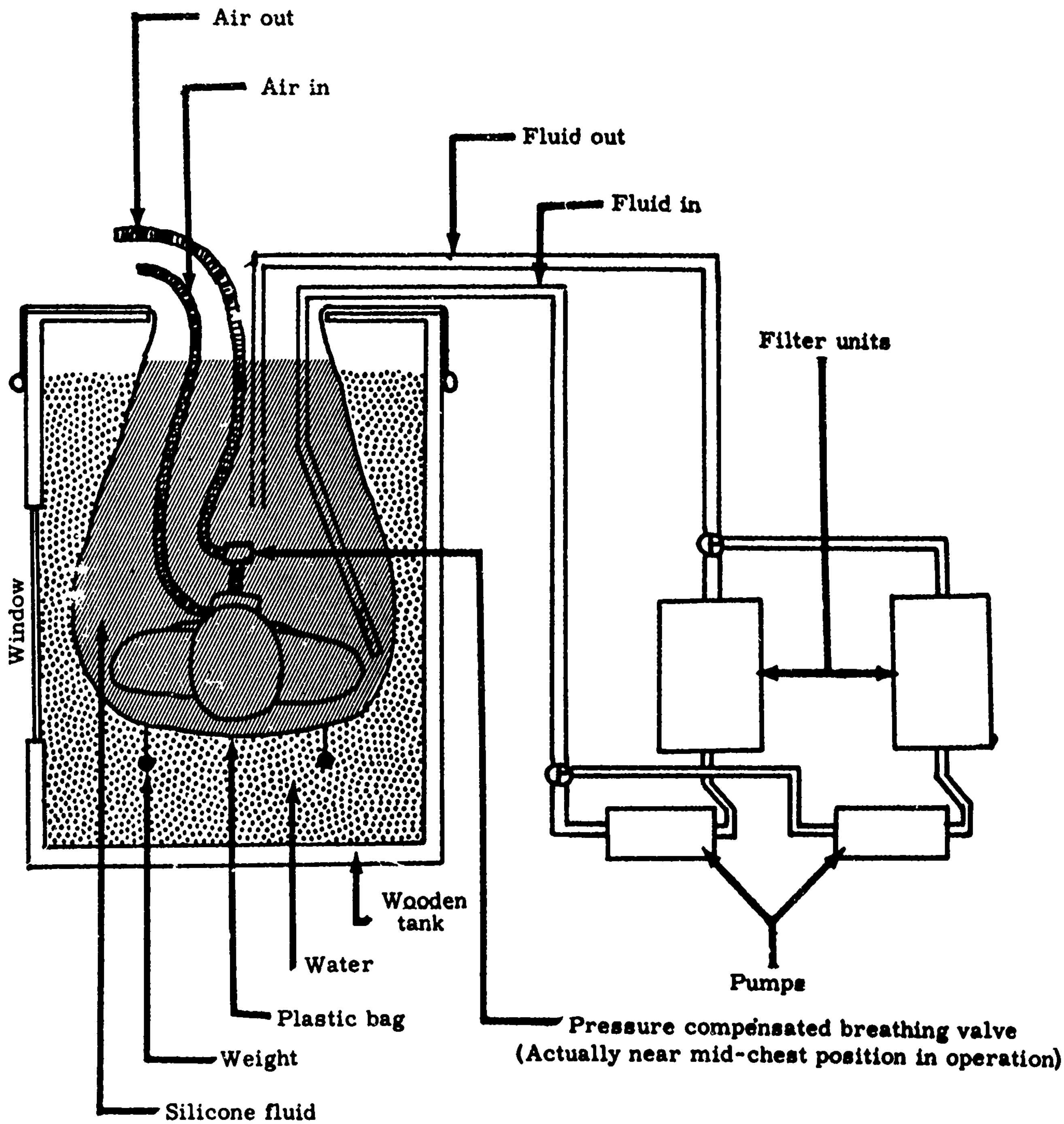
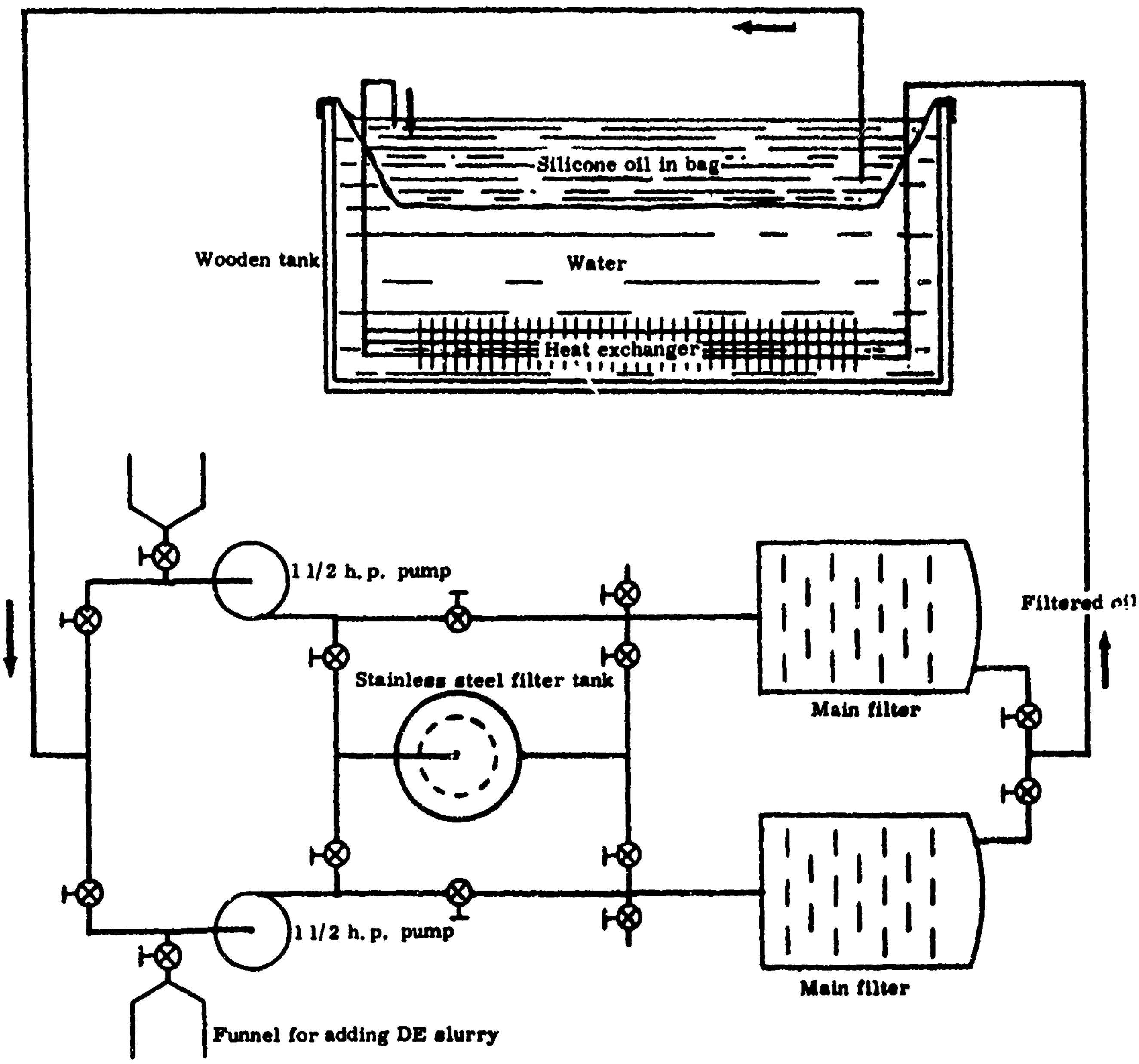


Figure 2. Diagram of main filter system.



Each filter was sealed in an enameled cylindrical housing and contained nine saucer-shaped disks approximately 15" in diameter covered with a Dacron septum, the total area of the bed being 25 square feet. Normally only one of the two main filters was in use, the second one being available in case of high contamination or failure. A precoat of four pounds of Johns-Manville Fibraflow 11 c, a diatomaceous earth-asbestos fiber blend, was deposited on the filter septum. This left a layer of approximately 1/16" to 1/8" thickness on which the filter cake was built. A slurry of activated charcoal and Johns-Manville Celite 545 (a relatively coarse grade of diatomaceous earth) usually 1/2 pound and one pound of each, respectively, was added to the filter cake three to four times a day.

There was also a stainless steel tank, ten inches across, mounted with the main filters; any desired proportion of the oil could be sent through this unit, which was charged with activated charcoal and/or Drierite. This was used to increase the water removal capacity as in case of high perspiration, and removal of odors, such as those from certain rubbers and plastics which might have contaminated the oil.

The third filter unit, named the "vacuum cleaner" was used to clean up spills, any urine that was lost during urination, and during routine skin hygiene. It was similar to the stainless unit on the main filters, and had its own pump and base connections. It also used a Dacron bag which held diatomaceous earth and Drierite. The "vacuum cleaner" was run intermittently and was used as a heater for the oil on occasion.

The oil, after leaving the filters, passed through 1 1/2" diameter Tygon tubing to a heat exchanger. The work of pumping the viscous oil through the filters caused the oil temperature to rise, and this heat was taken out in the large mass of the water tank through a simple heat exchanger. The heat exchanger, three parallel copper tubes with aluminum fins along their eight feet length, was situated in the water in the tank about six inches above the bottom. This resulted in the oil coming from the filter unit being the same temperature as the water surrounding the bag. All temperature control of the oil was by the temperature of the water in

the tank. The tank water temperature was controlled by adding cold or hot tap water and with a 1250 watt heater in the water filter system, and two 500 watt underwater lights.

The flow of oil was from the head of the vinyl bag through large bore Tygon tubing to the filter pump, through the filters and then through Tygon tubing into the heat exchanger and finally discharged into the foot of the bag.

It was necessary to maintain the bath temperature at a euthermic level while not allowing the subject to sweat. Early studies involving the use of silicone fluid in burn therapy work had indicated a bath temperature near 30° C would be desirable. Air studies indicate that skin temperatures of approximately 33° C in a resting man are associated with the onset of sweating. Since skin temperatures would be close to those of the bath it was thought that this level should not be exceeded. One must also take into account the variations in the pathways of surface heat loss or transfer which occur in air (and water) that would be different in the case of the silicone fluid. It was decided the bath temperature must however fall into the 30-33° C band tempered by subject comfort and physiological responses. Actual operating experience with two subjects -- one for 16 hours, and the other for 120 hours -- showed that the correct temperature band was 31° C to 35° C. It was necessary to run above 33° C at night while the subject slept, and below 33° C during the more active waking hours.

Preliminary information indicated that the fluid filtration system would add heat to the circulating oil in sufficient quantities to raise the effluent temperature above 40° C, making some amount of cooling essential. To accomplish either cooling or warming as necessary to maintain the bath within the narrow band required, a large area heat exchanger was placed near the bottom of the water tank, as shown in Figure 2. The large volume of water in the tank (800 + gallons) served to buffer any rapid changes in the oil temperature as monitored by strategically placed thermistors in the oil bath. As changes in bath temperature became necessary, hot or cold water was added to the tank near the heat exchanger. To prevent tank over filling and to speed responses a siphon was usually run at the

same time water was added. A water heater (1100 watts) in the water tank filtration circuit and two 500 watt underwater lights could also be turned on or off to assist in controlling the water temperature. When a rapid increase in bath temperature was needed the small portable "vacuum cleaner" filtration unit was allowed to run in addition to the layer unit. This served the purpose of both warming and supplementing the filtration.

As a final check on the appropriatness of the bath temperature the subject's core temperature as measured by a rectal thermistor was monitored nearly continuously. Shifts and trends in rectal temperature were decisive in any action taken to alter bath temperature.

Subject comments lead to the conclusion that a certain amount of layering was occurring in the bath despite flow rates in excess of 20 liters per minute. Since it was not desirable to mechanically stir the bath, an alternate solution was incorporated early during the 5 day submersion. A length of 1 1/2" O. D. copper pipe with a series of graded holes was added to the bath inlet and outlet lines. The holes distributed the flow across the depth of the bath rather than one high-low point near the bottom of the bath as was the case before.

The tank water temperature was always somewhat lower than the oil bath, hence when the subject rested on the plastic bag this coolness was noticed. To improve subject comfort, occasionally warm water was sprayed directly on the outer surface of the bag. This warm water tended to remain near the water surface allowing the usual heat exchange to occur near the bottom of the tank.

Tank water, oil bath and subject rectal temperatures were monitored through use of Yellow Springs Instrument interchangable thermistors and a digital readout thermometer (Digitec - United Systems). Temperatures were recorded at least every hour and frequently every 30 minutes throughout the submersions.

HEAD COVERING AND BREATHING SYSTEM

Because of the nature of the silicone fluid and the resultant difficulty anticipated in attempting to obtain "leakproof" facial or neck seals with partial or full face masks, a type of helmet-suit system was used in conjunction with a pressure-compensated exhaust valve. The criteria used in selection of the helmet-suit system were: subject safety, comfort, visibility, submersibility and compatibility with the breathing system. The open constant flow breathing system served the dual purpose of supplying the subject's respiratory needs and furnished a depth-pressure balanced "air bubble" in the helmet portion to dam back the fluid from the facial area.

Although several types and combinations of types of helmet systems were tried during preliminary submersion trials and the six hour training experiments, the one finally selected and used almost exclusively during the silicone fluid submersion experiments consisted of a full-face mask (MSA Clear-vu) which had been sealed with neoprene cement to the head portion of the rubber "dry" suit. The upper arms and chest portion of the rubber suit were retained to serve functionally as an extension of the helmet and help in the maintenance of the breathing - pressurization "bubble" during submersion. The arrangement in principle was like a soft form-fitting bucket which was inverted to trap air around the face and head. The suit was custom fitted to the subject, but the suit was by no means leak proof. The upper torso and neck area of the submerged subject was bathed in the silicone fluid. Stagnation of the fluid under the suit and the potential development of skin irritation was avoided by frequent attention to skin hygiene. Occasionally a diver's weight belt was laid across the lower chest of the subject to assist depth positioning. Abrupt loss of air from the system could mean flooding the entire helmet and face mask since no true seals were used.

Early tests using a helmet with a loose fitting plastic skirt extension (no neck seal), while being subjectively more roomy and comfortable than the dry suit combination, proved to be so bouyant that approximately 25 pounds of added weight was needed to sink it. This weight made subjects feel so insecure in trial runs that prolonged submersion in this system did not appear feasible.

The air was supplied by a pair of carbon vane pumps (Gast Manufacturing Co.) suspended above the submersion facility. The pumps could operate singly or in series and had an output of approximately 1.3 cubic feet per minute each. The air flow was continuous despite the back pressure developed by the depth of the pressure-compensated breathing control valve which was located in the exhaust line. The pressure-compensated breathing control valve used was of a type designed by Seeler (Seeler, 1964) and it fixed the pressure of the helmet "bubble" at a level selected by subject variation of the depth of the valve in the fluid. The negative pressure breathing usually associated with head-out immersion studies and the resultant circulatory unbalance leading to diuresis, etc., were avoided by positioning the valve near the mid-chest level. There was no single correct breathing pressure. We suspect there is no such pressure in a liquid medium at 1 G.

Even though the subject's respiration rate and tidal volumes were generally low, occasionally the instanteous flow rate would exceed the pump output. To correct this problem a balloon plenum was tied into the incoming line to compensate for the increased instanteous demand associated with sighing and deep breathing.

Since it was not desirable to allow the exhaust air to bubble up through the fluid, a line was connected to the exhaust valve to return the flow to the laboratory environment. This also permitted sampling of the mixed effluent for gas analysis. To prevent fluid collection in this line a two quart trap was installed. Throughout the breathing system either 1 1/4" (I.D.) wire-supported flexible plastic hose or 1" (I.D.) Tygon tubing was used.

For a short period during the five day submersion a demand regulator-compressed air breathing system was tried. This system was abondoned due to a loading failure of the demand regulator in the viscous silicone fluid.

SKIN HYGIENE

The objective of the skin hygiene program was to prevent the development of either maceration, irritation, or infection during prolonged submersion. Previous to entry into the silicone fluid subjects were required to take three showers a day for three days, using a germiseptic detergent (pHisohex - Winthrop) to remove sebaceous secretions and generally lower the skin bacterial count. In addition, head hair was cropped to a length of approximately 1/4 inch.

In order to prevent maceration of the skin in silicone fluid it is necessary to maintain the water content of the fluid at a very low level (100 ppm recommended by Dow Corning). The major source of water was sweat excreted by the subject and since it was necessary to maintain the bath temperature at a point near the sweating level of skin temperature it was critical to remove sweat as it accumulated at the skin-oil interface. Because of insolubility and other physical factors, sweat tended to form beads on the skin which would remain unless dislodged mechanically. Once dislodged into the recirculated fluid, water was removed in the filtration system. To perform this task the subject was required at least four times each 24 hour period to manually scrub over all reachable areas of his body with either a natural sponge, soft bristle brush, or his bare hands. The sponge was the most satisfactory and the most frequently used method. A clean, dry sponge was handed to the subject, who during scrubbing squeezed out any oil-water emulsion trapped in the process directly into the bath effluent line. The subjects were observed rubbing their bare hands particularly over the extremities as some tickling sensation developed with the accumulation of the beads of sweat. Occasionally the mobile inlet to the "vacuum cleaner" filter unit which had been equipped with a rubber brush tip was run over the body both to dislodge and suck away water droplets.

After some forty hours of the longer immersion it was discovered that additional attention must be paid to hygiene under the area covered by the subject's

trunks. Trunks were removed, the area directly scrubbed and clean trunks donned concurrent with the total body scrub. Occasional removal of the helmet system for breathing system relief allowed cleansing of the head thoroughly and frequently enough to prevent maceration or irritation from developing. The sponging procedure included the shoulders and neck without removal of the soft rubber head covering.

FEEDING

Subject feeding while submerged was accomplished with dual concentric tubes. The outer tube (1/2" I. D. Tygon) was sealed over the oral area of the faceplate. This tube was long enough (3 feet +) to protrude out of the oil bath when extended, and since it remained in place during the experimental periods, it was stoppered to prevent loss of air. At feeding time this tube was elevated clear of the fluid, cleaned, and the smaller inner feeding tube was inserted along the length of the outer tube until the subject was able to grasp it in his mouth. Prior to insertion the food tube was attached to a polyethylene bag containing the food to be consumed. With the inner tube in position the subject manually compressed and released the food bag to force the contents into his mouth. The feeding tube was either 3/8" O. D. Tygon or, preferably, 1/4" O. D. rigid polyethylene (Polyflow) tubing. To assist in control of the flow of food in either direction in the feeding tube the subject could either raise, lower, or maintain manual pressure on the food pack, and if the tube escaped from the mouth, the mask pressure would curtail flow of food into the mask area.

No attempt was made to feed solid foods through the feeding tubes. Although a feeding schedule and diet were prepared in advance, we allowed considerable free choice in what items were consumed, and at what time. This freedom was overruled when an increase intake of either fluids or nutriments was desirable.

WASTE COLLECTION

The major concern with the collection of wastes from the submerged subject was to prevent or minimize the loss of urine or fecal material into the bath. Since no defecation occurred, even during the 5 day experiment, only urine collection was necessary.

Two methods of urine collection were used. The first system was basically an external catheter composed of a condom sealed to a Tygon tube which lead to a low pressure reservoir attached to a vacuum pump. With the condom in place and hand held to prevent leaks, a slight negative pressure was applied through a shutoff valve to assist raising the urine up and over the bag support frame some three or four feet above the subject. At the termination of urination the subject pinched off the condom as it was removed to prevent loss into the oil and handed the assembly out of the bath to the experimenter who allowed any remaining urine to flow into the trap for subsequent volume measurement and addition to the 24-hour collection.

During the latter part of the 5 day submersion a second system was used. In this the subject simply voided directly into a plastic bag which was held tightly to the glans with the fingers. When finished the subject slipped the bag back over the glans, pinched it off, and handed it out to the observer. Generally, when this method was used the subject assumed a semi-sitting position to assist complete emptying of the bladder. The method was not quite as successful in keeping urine out of the silicone fluid or silicone fluid from the bag, however, the subject preferred the simpler method. In each urine collection any of the specimen lost into the bath was picked up by the mobile intake line attached to the portable "vacuum cleaner" filtration unit. Since urine (as well as sweat) remained in isolated drops in the silicone oil, it could easily be seen and swept up by the cleaner.

For defecation we were prepared to collect the specimen in a large plastic bag which was to be pulled up over the rectal area when the subject was in a flexed position. If considerable oil was mixed with the feces, separate treatment of the fluid was anticipated. An alternative method utilizing the invertible mitten principle used in spacecraft was considered as a good alternative. The exploring inlet to the vacuum sweeper would be used to police up any feces lost to the bath.

To minimize the liklihood of defecation, a pre-submersion soapy-water enema was given to each subject. In addition, food intake both before and during submersion was limited to low residue foods.

Immediately after the 5 day run the subject defecated normally, and observed no change in bowel habits thereafter.

COMMUNICATION AND ENTERTAINMENT

We were well aware that perhaps one of the greatest potential problems would be keeping the subject occupied and his mind off of his semi-isolated state for a period of up to 5 days. To accomplish this a number of stimulating input channels were used. Television, radio (including FM stereo), tapes, movies, telephone, and voice communication channels were used. Any one of the various entertainment media were selected at will by the subject.

The television was suspended above the submersion bag by a movable frame and the movie screen was clearly visible to the submerged subject. Some early concern over viewing difficulties due to the optical properties of the faceplate-oil-air interfaces proved unwarranted as both television and movies were clearly seen. The audio portion of all of the entertainment media was received by the subject through speakers submerged in the oil bath.

A small dynamic microphone was cemented inside the helmet faceplate for subject use. Subject-experimenter communications were always kept open and either party could at any time override any of the entertainment media.

SILICONE FLUID TESTING

Testing of the silicone fluid was in keeping with the program established by Dow Corning to meet the requirements of new drug usage under the IND program of the Food and Drug Administration. This quality control program included bacteriology, qualitative checks, quantative chemical tests, and tests for irritants.

Qualitative tests

Frequent checks were made by the experimenters for clarity and odor of the fluid by visual and olfactory examination. The development of turbidity indicated the presence of water in increasing amounts. Odor served as an immediate index of bacterial contamination acting on nitrogenous waste products, or contamination with volatile plasticizers or other odorous contaminants. At the first sign of change in either quality of the fluid, additional or fresh filtering capacity was initiated. Water content was also determined quantitatively by Dow Corning on strategically collected specimens. The results given in Table I indicate a water content slightly higher than recommended, however, not apparently incompatible with subject hygiene.

Chemical tests

Through the co-operation of the Medical Products Division of Dow Corning a complete quality control check was made on several specimens of both used and reprocessed fluid before, during, and after the experimental period. The results of these tests are presented in Table I. The results of the ultraviolet absorption tests indicate the presence of unidentified aromatics. It has been suggested that these represent plasticizers from the PVC (polyvinyl chloride) bag. Several other possible sources of aromatics were available including Tygon tubing and neoprene cement used in the helmet-suit construction.

TABLE I

Chemical testing of silicone fluid

Sample	Date Rec'd at Dow Corning	H_2O ppm	Quality Control	Ultraviolet Absorption Optical Density 2250 Å	Ultraviolet Absorption Optical Density 2750 Å	Contaminate
2 1/2 days in vinyl bag submersed in H_2O	9-29-65	337	(1)	8.50	1.188	Aromatic Unidentified
10 days in vinyl bag submersed in H_2O	9-29-65	234	(1)	20.72	2.84	Aromatic Unidentified
Post 16 hour immersion fluid	3-31-66	330	(1)	4.0	.600	Aromatic Unidentified
Reprocessed fluid(pre 5 day submersion)	4-02-66	600	(1)	4.5	.660	Aromatic Unidentified
Reprocessed fluid (pre 5 day submersion) (duplicate)	4-02-66	400	(1)	4.3	.648	Aromatic Unidentified
Post 5 day submersion bag fluid inlet	4-08-66	420	(1)	(2)	(2)	(2)
Post 5 day submersion bag fluid inlet (duplicate)	4-08-66	400	(1)	(2)	(2)	(2)

(1) Passed standard quality control testing for D. C. 360 Medical Grade Fluid, 100 cs., except for ultraviolet absorption.

(2) Samples lost.

In addition, pre- and post-submersion blood and urine samples obtained from the "5 day" subject were analyzed for silicone content. The results of these tests (see Table II) clearly show that the absorption of silicone fluid into the body is unmeasurably small. The small amount present is probably the result of handling since the pre- and post-submersion samples contain the same or less silicone fluid.

Bacteriological tests

It was necessary to maintain a bacterial count of less than 400 organisms per milliliter of fluid. Using isolation techniques 0. 10 cc of undiluted fluid was cultured on duplicate fresh blood agar plates and incubated at 37° C for several days. Plates were observed for growth each 24 hour period and final count was taken to be represented by the the number of existing colonies at 96 hours. Blood agar was selected for use because it was thought to be the best all-around nutrient medium where differential analysis is not needed. The fluid samples cultured were taken mid-stream in the filtration system effluent flow. Cutures were taken at the end of the reprocessing period following the shorter submersion; at 24 hours, 48 hours, and 90 hours during the 120 hour submersion; and after it. Generally, no distinct growth was visible until after 48 hours of incubation. The results and estimated numbers of organisms are summarized in Table III.

Irritants testing

Using a method developed by Dow Corning, multipoint injections of control fluid were made into laboratory animals (rabbits). Also reprocessed fluid and normal saline were injected. In all cases only mild transitory reactions occurred at any of the injection sites. All of these cleared by the end of a 72 hour observation period. Additional information concerning the methodology of this testing procedure must be obtained from Dow Corning Medical Products Division.

TABLE II

Tests of blood and urine for silicone

Specimen	Date	Analysis
Urine, pre-submersion	4-3-66	88.9 ppm Silicone
Urine, post 5 day submersion	4-8-66	41.8 ppm Silicone
Blood, pre-submersion	4-3-66	3.0 ppm Silicone
Blood, post 5 day submersion	4-8-66	3.0 ppm Silicone

TABLE III

Bacterial content of silicone fluid

Incubation Time		Pre Submersion	24 hr.	48 hr.	90 hr. *	Post Submersion
		(Number of colonies/0. 1 cc undiluted fluid)				
24 hrs.	Plate A Plate B	No visible growth	No visible growth	No visible growth	No visible growth	No visible growth
48 hrs.	Plate A Plate B	No visible growth	No visible growth	No visible growth	31 contam.	No visible growth
72 hrs.	Plate A	2	2	4	46	3
	Plate B	3	4	6	contam.	2
96 hrs.	Plate A	2	2	5	46	3
	Plate B	3	4	6	contam.	2
Est. total No. of organisms per cc.	Plate A	20	20	50	460	30
	Plate B	30	40	60	contam.	20

* Following slight skin irritation

PHYSIOLOGICAL TESTING

During the runs, rectal temperature, pulse rate, oxygen consumption estimation, fluid balance and dietary intake were monitored. Comparative physiological testing was performed pre- and post-submersion.

Tilt table test

Immediately before and after all 5 submersions all subjects were given a ten minute, 70° tilt table test. Anticubetal blood pressures were obtained every 30 seconds using a manually operated mercury or aneroid sphygmomanometer on each arm. Synchronous recording of heart rates were obtained for the tilt period (except in one case in which the electrodes were lost during the submersion). The post-submersion tilt tests were performed near the submersion facility allowing stretcher transport of the subject to the tilt table without his exertion or having assumed a vertical position.

Fitness test

Pre- and post-submersion fitness testing was performed on the subject who made the 120 hour submersion. The Balke treadmill test was used. Oxygen consumptions were determined at critical points during the test using a standard Douglas bag collection method. Continuous cardiotachometer records were obtained.

Fluid balance

Water immersion simulation of weightlessness has usually produced diuresis with concomitant electrolyte shifts. A careful log was kept of fluid intake and urinary output. Each 24 hour urine collection was pooled, volume measured and specific gravity determined. In addition, a pre, mid, and final 24 hour pooled urine specimen was analyzed for electrolytes. During the last 2 days of the 120 hour submersion, the subject was encouraged to increase his fluid intake even though no frank diuresis had been observed.

Other procedures

Packed cell volumes (hematocrits) were performed before and after the 5 day submersion.

Dietary intake was logged for daily caloric level. The subject's weight was determined before and after the submersion on a platform scale accurate to ± 5 grams.

RESULTS

The experimental program may be viewed as having two preliminary phases leading to a concentrated effort directed at the accomplishment of the final 5 day (120 hour) silicone submersion. The first phase included three 6-hour water submersions which served the purpose of subject and experimenter training. Procedures were modified for the second phase which included a trial silicone fluid submersion. The first silicone fluid submersion lasted 16 hours and provided information vital to the success of the 120 hour submersion.

Three male subjects, all trained in SCUBA techniques, performed 6-hour water submersion training runs. Two of these people were to later become the subjects in the silicone fluid experiments. Some personal and anthropometric data for them is listed below.

Subject	Race	Age	Ht.		Wt.		SA	Comments
		yrs.	in.	cm.	lbs.	kg.	m^2	
A	Cauc.	28	74	188	170	77	2.00	experienced diver, lab technician
B	Cauc.	43	68	173	183	83	1.96	SCUBA trained, researcher
C	Cauc.	17	68	173	133	60	1.71	SCUBA trained, student

Water submersion training trials

Pre- and post submersion tilt table tests were performed on all three subjects. The blood pressure and pulse response to 70° tilt for 10 minutes are given in Table IV. Examination of the values obtained disclose no significant effect of the

TABLE IV

Blood pressure and heart rate responses to 70° tilt before and after 6 hour water submersion.

	Subject - B 3/25/66						Subject - A 3/3/66						Subject - C 3/8/66					
	BEFORE			AFTER			BEFORE			AFTER			BEFORE			AFTER		
	R	L	HR	R	L	HR	R	L	HR	R	L	HR	R	L	HR	R	L	HR
Level	128/90	134/90	76	130/92	122/76	85	120/71	112/71	68	126/80	130/72	not avail.	106/46		75	118/68	112/54	60
0		150/100	96	134/100		110			78			"	94/70		100	126/84		95
30"	138/100		88		120/80	96	114/80		90	128/88		"			90		118/88	92
1'		144/104	84	136/96		96		118/88	86			"	94/78		90	122/92		88
30"	136/106		90		136/104	94	118/86		93	118/84					91		116/82	92
2'		146/106	86	136/106		85		118/88	92			"	98/76		98	124/92		93
30"	138/106		88		140/110	87	118/82		94	124/90		"			107		118/84	98
3'		148/108	88	142/104		91		116/86	88		126/82	"	98/78		98	136/86		104
30"	140/108		85		146/112	90	122/90		90	114/84		"		92/80	93		114/80	94
4'		150/110	90	134/104		80		116/84	90		118/80	"	102/78		99	116/86		102
30"	144/110		87		138/108	84	122/86		92	112/90		"		96/80	94		112/78	106
5'		144/110	87	134/106		94		118/86	88		118/86	"	98/82		92	102/94		108
30"	140/110		93		138/110	86	110/90		94	114/90		.			93		110/80	108
6'		146/114	90	130/108		90		116/88	100		126/84	"	110/84		95	108/86		103
30"	136/112		88		138/112	90	122/92		95	108/102		"		106/84	100		98/74	107
7'		148/116	88	132/112		94		118/88	88		128/88	"	108/86		98	108/86		103
30"	140/112		85		140/114	94	114/80		86			"		104/82	103		102/82	103
8'		154/114	87	130/112		98		116/84	90		132/90	"	110/84		95	110/86		98
30"	136/108		[illegible]		138/112	97	122/96		90	106/96		"		106/82	105		100/76	103
9'		154/116	85	128/108		94		118/82	86		108/94	"	108/94		98	104/80		102
30"	140/112		88		134/108	84	114/84		94	104/96		"		105/84	106		96/74	114
10'		154/116	86	138/106		96		118/80	90		118/88	"	104/86		100	100/82		106

6 hours of submersion on either blood pressure or pulse rate. Contrary to some authors,e. g. Graveline (Graveline and Jackson, 1962), 6 hours of submersion did not produce cardiovascular effects detectable by this means. This, we think, may be accredited to the fact that the subjects were totally immersed with balanced breathing. Diuresis, which may be seen in 6 hours of immersion where there is negative pressure breathing, failed to develop in any of the three persons tested.

Oxygen consumption determinations were made on submerged subject B by collection of mixed exhaust air in a Douglas bag. calculations based on oxygen content measurement with a Beckman Pauling analyzer gave $\dot{V}_{O_2}$'s ranging from .33 to .22 liters/minute. Respiration rates obtained visually on resting submerged subjects averaged 8-10/minute and heart rates averaged 60-70 beats/minute. Skin maceration was evident, particularly over thick skin areas, well before six hours had elapsed. The least maceration was noted on the youngest subject. The comfort temperature of the water bath averaged 33° C to 35° C for all three subjects. Fresh tap water was used in the plastic submersion bag, and tap water was used in the large wooden tank.

16 hour silicone fluid submersion

Knowledge gained during the three 6-hour water submersions regarding instrumentation and procedures were implemented and a trial silicone fluid submersion was initiated with subject B. The established goal was a submersion of 48 hours, however, the experiment was terminated after 16 hours due to subject discomfort with the head covering and breathing system.

Pre- and post-submersion tilt tests (Table V) give no indication of deconditioning having occurred. There is no narrowing of pulse pressure. Unfortunately, comparative pulse rates during the 10 minutes of 70° tilt are not available as the electrodes were not servicable following the 16 hours of submersion.

TABLE V

Tilt table test before and after 16 hour silicone submersion

	Pre-submersion blood pressure			Post-submersion blood pressure		
	R S/D	L S/D	H. R.	R S/D	L S/D	H. R.
Level	128/88	126/82	62-80	128/108	126/90	not avail.
0			76-86		140-110	"
30"	128/100		72-86	148/116		"
1'		122/92	76		152/110	"
30"			82	148/118		"
2'			72		146/114	"
30"			80	136/114		"
3'		124/104	74		138/108	"
30"	142/110		72	134/114		"
4'		130/108	74		140/102	"
30"	142/112		80	144/116		"
5'		132/106	78		138/112	"
30"	132/110		80	138/114		"
6'		130/108	72		140/112	"
30"	138/110		76	136/114		"
7'		130/108	82		136/114	"
30"	136/112		80	140/116		102
8'		134/108	82		128/112	
30"	136/108		82	136/112		not avail.
9'			88		132/112	"
30"	138/110		76	142/114		"
10'		134/108	80			"

Urine was collected during the 24 hour pre-submersion control period and during the 24 hour period comprising the 16 hours of submersion plus 8 hours of recovery. Fluid intake for the two periods was also recorded. The volume of the pooled specimens were obtained and the content of various electrolytes determined (Table VI). Although there was an apparent negative water balance, no frank diuresis associated with the submersion period was seen. There was some shifting of electrolytes. The ratio of fluid intake to urine output on both the control and the submersion period and the urine concentration (specific gravity) were essentially the same. The subject lost 3 pounds over the submersion period.

No skin irritation developed, however some eye irritation was noted by the subject. A very slight amount of maceration occurred. The maceration was restricted to the finger tips and areas of thick cornified layers. The euthermic bath temperature was 33° C to 35° C and little change was noted in subject core temperature (rectal) when this level was maintained. The post-submersion silicone fluid was only very slightly cloudy and odor free.

<u>120 hour silicone fluid submersion</u>

The major effort of the project was directed at the successful completion of a 120 hour continuous silicone fluid submersion. Subject C volunteered to attempt the prolonged submersion. The use of such a young subject was allowed on the grounds that he was known to be highly motivated and was considered to be sufficiently mature to withstand the psychological and physiological impact of the prolonged semi-isolation of submersion. The fact that the entire 120 hours of continuous submersion was completed speaks for the correctness of this selection.

During three days of intensive fluid reprocessing and testing, the bath was made ready for the subject. Samples of reprocessed fluid were collected for quality control testing by Dow Corning and bacteriological and irritants testing was initiated.

The 120 hour submersion began at 2 p.m. Sunday afternoon, April 3, 1966, and continued to 2 o'clock on the following Friday. During this period we maintained around-the-clock surveillance, with always at least two trained observers in the laboratory. Medical coverage was continuous since the laboratory physician slept in the building.

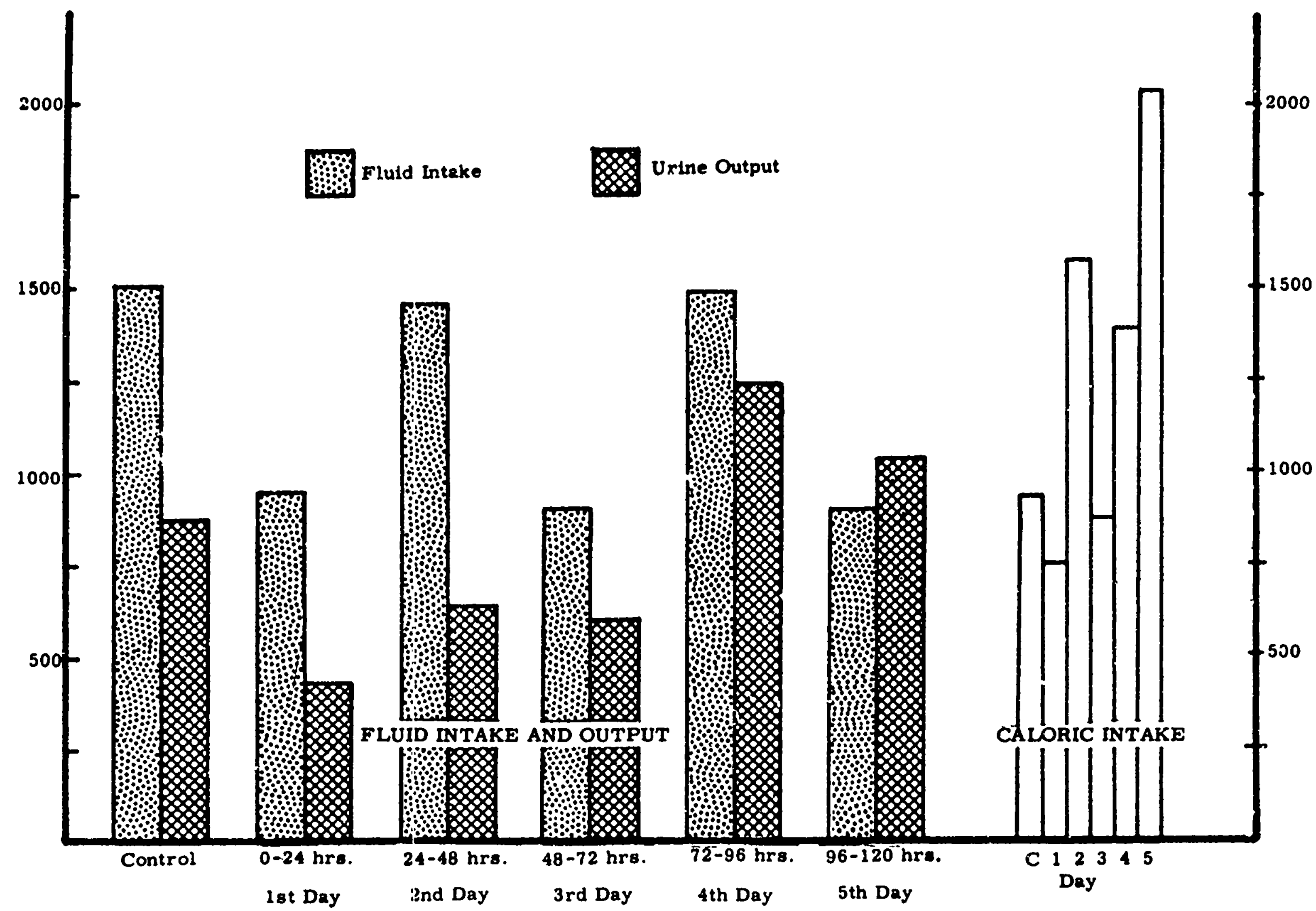
A diary taken from the experiment log book is reproduced as an Appendix at the end of the report.

The success of the 120 hour run was never seriously in doubt. In the first 24 hours the discomfort of the breathing system was the chief problem, and thereafter we used periodic head-out relief periods, and tried several different variations of breathing equipment -- each with temporary success.

The most valuable psychological measure was the arrival of visitors, friends of the subject, who made much of the confined and difficult situation the subject was in, and who helped, through teen-age chatter, to keep the subject's thoughts directed away from his inner discomforts. The first 24 hours were the worst. From then on, subject and observers were confident of being able to complete the entire scheduled period.

Since weightless simulation studies involving water immersion have a history of producing subject diuresis, an intake-output log was kept during the submersion period plus a pre-submersion control day. As can be seen in the bar graph, Figure 3, no diuresis occurred over the 5 day period. There is, however, a gradual increase in the urine output when compared to the fluid intake (per 24 hours) across the submersion period. Only on the 5th day was the output in excess of the fluid intake. The 24 hour pooled urine specimen data is given in Table VI. The specific gravity of the pooled specimens also do not indicate diuresis. Urine electrolyte measurements performed on the third and fifth day specimens show a decreasing content of Na^+ and K^+ and increasing Ca^{++} when compared to the control. Routine urinalysis results were not remarkable, however, there was a slight increase in white blood cells (WBC) in the later specimens. In support of the conclusion that the subject maintained a positive water balance there was only a

Figure 3. Fluid balance and caloric intake data during 120 hours of submersion.



2 vol % increase in the packed red blood cell volume (hematocrit) during the 5 days (46 vol % to 48 vol %). Also the total weight loss was less than 4 pounds for the period. The caloric intake was considerably less that customary for the subject (see Figure 3) and except for the 5th day was less than the estimated energy expenditure of the subject. Oxygen consumption measurements made by Douglas bag collections of mixed exhaust air showed an average energy expenditure of 66 kcal/hour or nearly 1600 kcal/day. Unfortunately urinary nitrogen excretion was not monitored. Periodic pulse rates were obtained using a photocell pick-up device. Rates ranged from 60 to 90 per minute depending upon amount of subject activity.

The degree of debilitation or deconditioning which occurred during the prolonged submersion can best be seen by observing the results of the tilt tests and treadmill fitness tests performed immediately before and after submersion. The same 70° tilt test as performed in the other experiments did in this case show a comparative narrowing of the pulse pressure associated with an increase in pulse rate in the post-submersion test. In Figure 4 the pre- and post-submersion left arm blood pressures and pulse rates are given. The comparable digital data (including right arm blood pressure) is given in Table V_a. During the latter half of the post-submersion tilt test the subject became nauseous, however, there was no real syncope.

The Balke treadmill fitness test, which entails an increase in work load of 1% grade change per minute at a constant speed of 3.5 mph, was performed before and after submersion. Periodic metabolism measurements were made using a standard Douglas bag collection technique during each test and a continuous cardiotachometer record was obtained. The decrease in the ability to perform work after submersion is evident in the results given in graphic form in Figure 5. After submersion the subject was able to work for only four minutes as compared to seventeen before submersion. The heart rate at this point (4 minutes) was 20% greater in the second test while the oxygen consumption was considerably less.

Figure 4. Blood pressure and heart rate responses to 70° tilt before and after 120 hour submersion

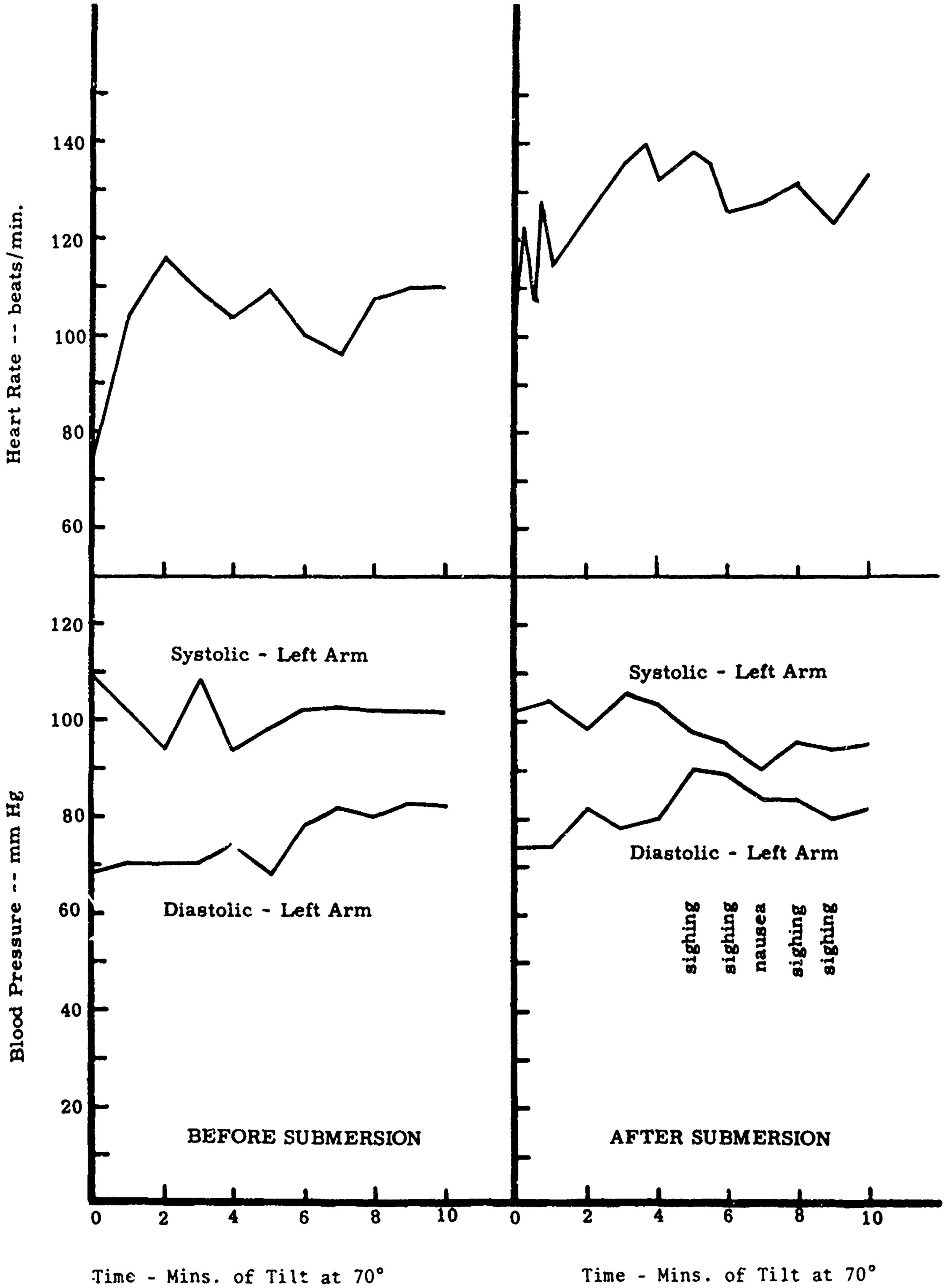
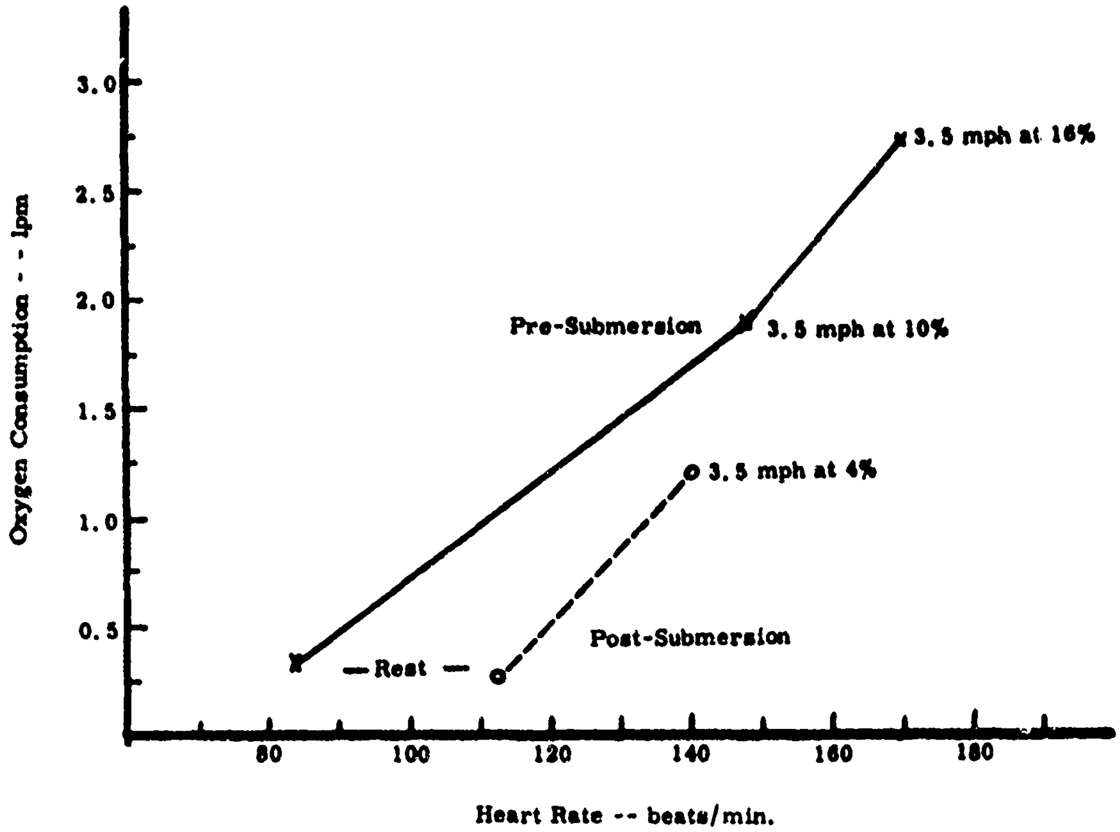


Figure 5. Balke treadmill test before and after the 120 hour submersion.



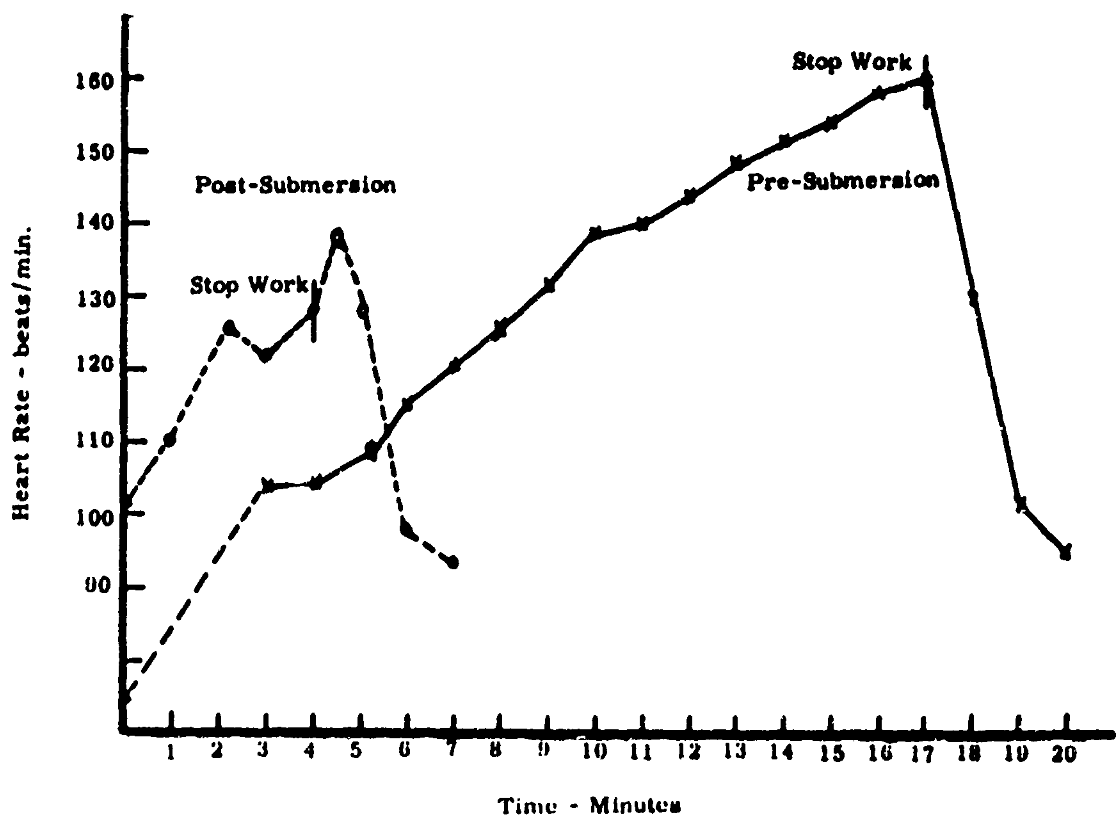


TABLE V_a

Tilt table test before and after 120 hour silicone submersion

	Pre-submersion blood pressure			Post-submersion blood pressure		
	R S/D	L S/D	H.R.	R S/D	L S/D	H.R.
Level	108/0	108/52	70-80	112/0	110/40	81-114
0		108/68	75		102/74	105
30''	106/10		96	110/70		108-123
1'		102/70	102		104/74	115-128
30''	106/54		108	106/76		120
2'		94/70	116		98/82	126
30''	104/64		112	100/80		132
3'		108/70	108		106/78	136
30''	106/60		105	104/80		140
4'		94/74	104		104/80	132
30''	100/66		103	100/76		132
5'		98/68	109		98/90	138
30''			110	106/76		136
6'		102/78	100		98/88	126
30''	98/68		102	102/78		132
7'		106/84	96-116		90/84	128
30''	102/70		109	98/80		132
8'		102/80	108		96/84	132
30''	96/64		106	98/80		126
9'		102/86	110		94/80	124
30''	102/76		112	104/80		124
10'		102/84	111-116		96/82	134

TABLE VI

Urine studies

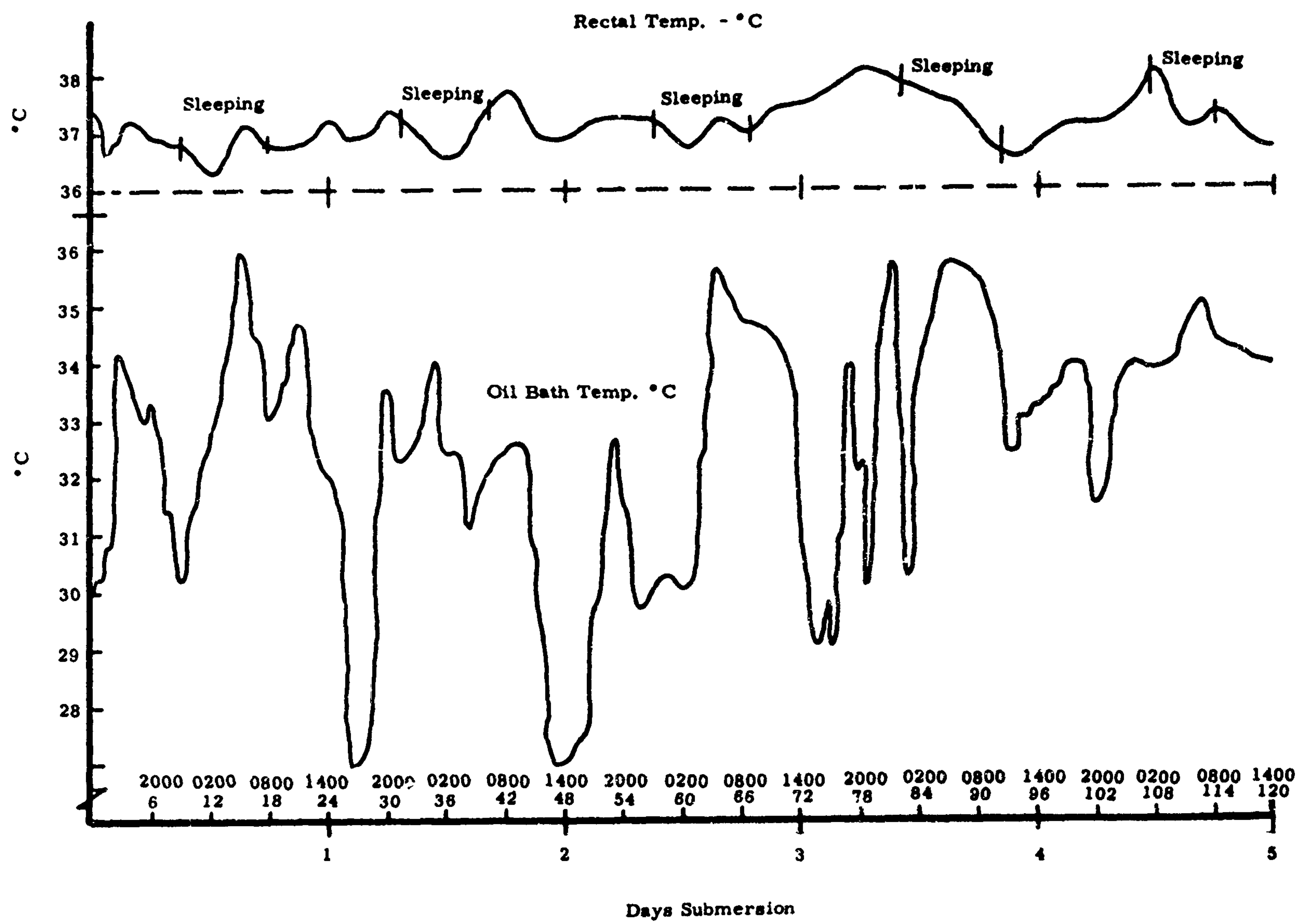
	Fluid Intake	24 hr urine vol.	Sp.Gr.	Na	K	Cl	Ca	Routine urinalysis
	ml.	ml.		mEq/vol			gm/vol	
16 hour 1st submersion								
Control	670	1200	1.025	312	7.8	241.2	--	Sug., alb - Neg. 2-6 WBC/hpf, occ. epi cell, mucous thds, few bact, 5-8 RBC/hpf.
16 hour submersion (16 hr. + 8 hr.)	480	990	1.024	186	50	162	0.11	Sug., alb. -Neg, 6-8 WBC/hpf, occ. epi cell, mod. bact., much debris.
120 hour 2nd submersion								
Control	1508	870	1.021	362	62.6	111.5	.078	Sug., alb. - Neg. rare WBC, occ. epi cell, mucous, few bact.
1st day	953	422	1.023					
2nd day	1461	638	---					
3rd day	904	595	1.029	144	38.8	112.8	.126	Sug., alb. - Neg, 5-10 WBC/hpf, few epi cell, loaded am. urates, many bact.
4th day	1486	1235	1.018					
5th day	888	1030	1.019	128	11.2	88.8	1.60	Sug., alb. -Neg. 10-15 WBC/hpf, occ. RBC, few epi cells, loaded bact., rare uric ac. xtls, mod Ca oxa. tripie PO_4

The resting heart rates are elevated strikingly after the 120 hour submersion. This finding is evident in both Figure 4 and Figure 5.

A plot of the subject's rectal temperature and the silicone bath temperature for the entire 120 hour submersion is given in Figure 6. The euthermic temperature was probably 33 ± 2° C as sweating became apparent when the bath reached 36° C and 30° C was too cool. Although there was more variation in the bath temperature than we desired, close observation will show that the major deviations were associated with a warming trend during hours in which the subject was sleeping and cooling during the more active afternoon and evening hours. Despite bath warming there is a tendency for the subject's core temperature to drop during the night. Since both rectal and bath temperatures follow diurnal cycles it is difficult to say how much the subject's normal patterns were influenced. The peaks in rectal temperature occurring from +72 hours to approximately +78 hours and again at +108 are unexplained. However, during the first rise the subject was removed from the bath for 15 minutes and examined by the laboratory physician. The subject was kept horizontal and did not exert himself during this. Since no apparent infectious process or other malady was found, the subject was returned to the bath and the experiment continued. A routine urinalysis examination performed at the time showed little indication of urinary infection. A very slight non-specific micropapular rash localized on the chest cleared after returning to the bath. At the end of the 120 hours the subject's skin showed no irritation and no remarkable maceration.

At any time throughout the 5 days when either cloudiness or an odor of the fluid was detected additional fresh filtering capacity restored the quality of the fluid. The results of the various silicone fluid tests are given in the section on silicone fluid testing.

Figure 6. Plot of rectal and bath temperatures during the 120 hours of submersion.



CONCLUSIONS

In summary, the major conclusions based on the results obtained are the following:

a. Silicone fluid can be used as a weightless simulation medium in prolonged immersion or submersion of nude subjects. Subjects can be kept free of skin irritation or maceration for long periods of time if diligent quality control of the fluid is maintained.

b. Any period of submersion up to 120 hours continuous need not result in the development of a negative water balance due to diuresis. This is thought to be due to the absence of negative pressure breathing in our experiment.

c. The most significant indicators of the extent of deconditioning occurring as a result of prolonged submersion was a higher resting heart rate and a reduction in the ability of the subject to perform a set regime of work, with a concomitant reduction of oxygen consumption for a given heart rate.

d. A narrowing of pulse pressure and increased pulse rate response to 70° tilt was not seen in submersions lasting up to 16 hours.

REFERENCES

1. GEROW, F. J., S. B. SPIRA, and S. LAW. Silicone immersion treatment of the badly burned patient The IIIrd International Congress of Plastic Surgery. Exerpta Medica International Congress Series No. 66, 1963.

2. GEROW, F. J., and R. S. WEEDER, M. D. Fluid silicone continuous immersion in the treatment of burns. Bulletin of the Geisinger Medical Center, 16:17-21, 1964.

3. GRAVELINE, D. E., and MARGARET M. JACKSON. Diuresis associated with prolonged water immersion. J. Appl. Physiol., 17:519-524, 1962.

4. ROWE, V. K., H. C. SPENCER, and S. L. BASS. Toxicological studies on certain commercial silicones. J. Indust. Hygiene and Toxicol., Vol. 30, No. 6, pp. 332-352, 1948.

5. SEELER, HENRY W. Underwater pressure-compensated breathing control valves for prolonged water immersion. AMRL-TR-64-130. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, December 1964.

APPENDIX

SILICONE SUBMERSION DIARY

5 day run - Subject C

Started at 1400 hours on 3 April 1966

4/3/66	First Day
1415	Trouble right away with leaking air from top of rubber helmet where joined to face mask. Oil inside, on face and hair, in eyes, and down exhaust hose.
1430	Subject is cold. Warming things. Trying to fix leaks in helmet on subject -- no luck.
1500	Pulled helmet and suit off subject. Subject sitting in oil up to neck. T_r still low. More warming. Subject listening to radio.
1530	Drank 4.2 fl. oz (124 cc) of orange-apple juice. Helmet back on.
1715	Drank a Coke -- 6 1/2 oz.
1800	Subject complains the bath is too warm. Starting to sweat. Cold water turned on in the tank. One leak still exists on right side of rubber suit. Trying to repair it.
1830	Cold water stopped -- siphon started to lower water level in tank.
2100	Subject watching TV. We had to disconnect one air pump (Gast) so that the subject could hear the audio sound from the submerged speaker. The air rushing by his ears was tremendous compared to any volume we could supply and very uncomfortable for the subject. Rectal probe dropped out at 1730 and we haven't instructed the subject to replace it as yet.
2115	Subject had 149 ml. of pea soup. Complained that it needed salt. Asked for some fruit juice.
2120	Subject had 125 ml. of orange-apple juice. Subject sat up to eat, but stayed in helmet. Two pumps were used when subject ate.
2130	Subject back to one pump (Gast) to watch TV. Pump unplugged from electrical outlet.
2145	Rectal probe replaced.
2200	Subject says breathing system is for the birds ! Only time he is comfortable is when he is sitting up.

2220 Took pulse rate with finger probe on right hand. Signal good.

2330 Subject unable to sleep because of valve. Feels comfortable sitting up. Thinks perhaps a harness arrangement under his arms will keep him at a comfortable level.

2330 Lowering level of water in tank in hopes of rounding out bag and lowering oil level.

2345 Back strap placed around subject to support him in a position in which he can sleep. Weight belt placed over his hips.

<u>4/4/66</u>

0025 Subject urinated; approximately 120 cc obtained. Very little urine lost. very little oil in specimen.

0040 Subject sleeping, t_r very slowly dropping.

0115 Tank water heater on.

0150 Subject wakes -- had him sponge himself off.

0200 No apparent maceration at 12 hours. Subject does not feel cool -- t_r continues slowly down, oil-water warming.

0225 Subject urinates approximately 3 oz. (Some oil in specimen -- possibly 5 cc.)

0330 Turned off one underwater light.

0415 Start cold water into tank. Subject's rectal starting back up and oil bath is warmer.

0500 Subject arouses out of sleep into sitting position crosswise in bag. Had been sweating on face "from hot air."

0510 Water turned off. Turned on other pump.

0530 Subject requests both pumps to cool face.

0645 Removed Seeler valve to offer subject some breathing relief. Main complaint -- ears tender, chest sore from breathing against valve.

0730 Trying new air supply arrangement. Subject reclines for a few minutes and it seems to be more satisfactory.

0815 Subject asleep.

0900 Subject wakes. Wants to eat. He has been complaining of positive pressure breathing and of rebreathing. Drank 124 mg. of fruit juice.

0930 Started siphon to lower water level to spread bag and give the subject more surface area. Watching TV. Air "T" tube moved to window.

1010 One of subject's friends came by to chat with him. Cheered up the subject a good deal.

1035 Took pulse rate -- 84 beats/minute.

1045 Rectal probe has slipped out again. Will have subject replace it when visitor leaves.

1050 Sister of subject and friends came by to cheer him up.

1055 All visitors gone.

1100 Mr. Frisch of Dow Corning visited lab. Talked with Dr. Webb, inspected submersion facility, saw procedures for testing oil.

1120 Subject urinated 190 cc. Accident -- allowed some urine to get into the fluid. Vacuum cleaner used to pick it up.

1130 Vacuumed the inside of the bag for 10 minutes. Vacuum off.

1150 Subject asked for an received a can of Rum Punch Metracal - 238 ml.

1200 Rectal has slipped out again. Subject sitting up in fluid talking with another friend that stopped by. It appears that it slips out when subject sits up. Will have subject replace it when visitor leaves.

1307 Turned off heater (H_2O) turned on cold water, and started siphon. Turned off room heater -- subject's rectal too high at 37.4. Subject asleep.

1335 Stopped H_2O in tank. Bath temperature cooled 0.6° C.

Second Day

1400 Subject urinated 97 ml.

1430 Stopped siphon on water in tank.

1445 Subject drank 126 ml. of fruit juice.

1500 Replaced Seeler valve with a straight through pipe with an adjustable valve on outside of tank.

1515 Discovered big air pocket in intake hose of oil filter system. Put two pumps on the line to draw air out. Can't seem to get much flow through the system. Pressure has gone up to 26 on filter gauge but still very little flow.

1530 Subject urinated 173 ml. (Used larger Tygon tube with no valve -- works better.)

1700 More friends arrive. Helps subject a lot.

1730 Brought subject out of fluid to give ears and lungs a rest from the air system. Ears are pink all over. Oil covers his head. Great relief from no resistance to inhalation or exhalation. His main problem has been exhale resistance against positive pressure in mask. On emerging

he felt giddy for a moment -- feels weak from being immersed for so long (27 1/2 hours). Also, there was urine trapped in trunks. Probably 20 to 30 cc. Cleaning up subject by wiping head, neck, arms, and chest with dry towel.

1800 Subject has eaten vegetable beef soup (1 1/2 cups), pudding (124 gm), hamburger (1/4 lb) while out of helmet.

1830 Cleaning up bag with vacuum cleaner unit. There was yellow fluid in drops near subject's hip area. Subject out of fluid for several minutes, lying flat on frame.

1910 Subject back in fluid. We are now making a suspension system to keep him afloat.

1930 Rectal probe reinserted. Bath temperature rather hot due to the big attempt to clean the fluid with not too much success.

1935 Running cold water in tank and siphoning at the same time to try to maintain the water level. Shut second filter pump off. Subject drank 126 cc of fruit juice.

2100 Started more cold water -- no siphon.

2105 Started small vacuum cleaner unit with Drierite added (1 lb.) attempt to see if it will remove the urine contaminated fluid.

2120 Cold water off, visitors continue.

2140 Both hoses drain-siphon to lower water level in an attempt to clear out area in bottom of bag that is adhering and cloudy. The main body of fluid is clearing nicely with both vacuum and main Baker filter going. Note some decrease in odor in fluid.

2200 Stopped both siphons.

2315 Last visitor leaves.

2400 Subject sleeping with no helmet.

<u>4/5/66</u>

0100 Room furnace turned up.

0150 Test Seeler valve -- requires 1 inch of water to operate (actually 0.8 in.). The operation pressure drops slightly as depth is increased.

0210 Pool water heater on, 2nd pool light on to bring up tank temperature.

0220 Have dry suit helmet system ready to put on. Subject however is still asleep -- will not put it on till he wakes.

0305 Subject wakes up rubs face, gets oil in eyes, wipes it out. Subject sits up, has to urinate. Tries hand-held plastic bag. Also, tr probe returned to position

0313 Subject urinates fairly successfully into bag, only a few drops in fluid. Urine volume - 190 cc of golden yellow (straw +), fairly concentrated. Approximately 3 cc of oil with urine specimen.

0320 Subject sponges body off with new dry sponge.

0340 Subject back to sleep.

0400 T_r continuing slow drop despite warming of tank water (diurnal?).

0450 Added more D. E. and charcoal to filtration system.

0715 Subject wakes -- sits up crosswise in bag.

0745 Subject urinates 275 ml. Uses hand-held bag -- loses a few drops. Apparently prefers this method.

0800 Washed off subject's face with pHisohex and rinsed.

0845 Ate 128 gms. of canned peaches.

0850 New (clean) trunks put on subject. Mild erythema under them.

0915 Sitting on edge of tank to don rubber suit. Feels giddy. Abort -- suit tore.

1015 Rectal temperature rising. Cold water turned on. Rubber suit nearly finished. Subject lying in sling watching a film.

1035 Second try with suit. Faint and "sick" when upright.

1040 New breathing system works fine. Subject comfortable.

1045 Change from one air cylinder to another, turn on second cylinder and the demand regulator ran full open and blew up rubber suit. Regulator is kaput.

1200 Trying new system with a plastic bag on the air intake between the Gast pumps and the subject. The output of the Gast is T'd to the stand tube which is in the bucket at the side of the tank.

1300 Subject still trying system. Ran hot water in tank to warm up bath. Faint and woozy. Needs to lie down.

1315 Subject ate 4 oz. of beans and ground beef through tube.

1330 All hot water gone. Raised tank to 27.2° C.

1335 Subject complains about pressure on his ears.

Third Day

1430 Subject urinated 190 ml.

1445 Siphoning bottom of tank to lower bag and warm up bath.

1600 Subject asleep.

1610	Camerman here to take more movie footage -- hygiene, feeding, bag cleaning, etc.
1620	Drank 238 ml. of Metracal -- was recorded on film. Present breathing system is fairly good -- only problem is sore ears when head under because he prefers low (probably negative) pressure in helmet, and head straps up tight. He will lie out straight to watch movie, relax, but needs a head sling.
1645	Resting, seated crosswise.
1730	Having movie taken of subject cleaning himself, watching movie, pulse recording, temperature monitoring, vacuuming the inside of the bag, etc.
1800	Finger pulse taken -- 81 beats/minute.
1815	Subject taken out of his dry suit, sitting in bath with sling under his head, watching TV.
1900	Subject complains of being too warm. Increased f. w of filter pumps, turned off one underwater light. Turned furnace down.
2000	Subject resting in sling.
2050	Started cold water into tank as subject's t_r is going up. Unexplained at this time as to why t_r is down and t_t is stable. Subject watching TV -- exciting game of hockey.
2100	Visitors arrive.
2130	Subject given pre-cleaned and dried sponge rubber ball to squeeze for exercise.
2130	T_r continues to rise slowly even though oil is relatively cool.
2200	Visitors still here to amuse subject.
2245	Subject drinks 218 ml. Metracal.
2300	Subject still entertaining visitors (or vice versa).
2325	Subject urinated 275 ml. straw +.
2330	Scrubbed bag with vacuum -- subject's other pair of trunks still wet.

<u>4/6/66</u>

0045	Subject fitted back into helmet system. Ear pads made from pre-washed, pre-dried white foam donut shaped rings. Rings are placed in head area before entry and held in place by pinching helmet on outside until subject in place. Then experimenter runs hand up to place ear in ring (vice versa). Usual fussing with leaks, etc. Subject appears comfortable. Replace t_r probe. <u>Note</u>. After sling material removed from tank there was no odor in bag.

0115 Subject sits up in bag crosswise. Complains breathing air too hot. Also ear pads do not entirely keep helmet off of ears.

0130 Fan installed to air cool air supply pumps.

0145 Subject returns to lying position and not very quietly by fussing with valve level, etc., occasionally.

0245 Subject has been dozing for short periods. Arouses to adjust this or that -- mainly bubble or Seeler valve level. Must be some eye irritation as subject makes move to rub them when he arouses.

0320 Subject returns to sitting position.

0330 Helmet and suit removed per request.

0410 Subject put into sling. Since the sling material used before smelled, a nylon cloth was tried but not satisfactorily as it becomes too slick in the oil and subject slides down and puts pressure under arms.

0421 Old sling put back -- it has been washed and dried.

0430 Subject resting quietly, but sweating. Temperatures checked at 1/2 hour and oil is too warm. Has raised 3° C in last 1/2 hour. Reason not detectable as no changes for temperature in last 2 hours. Everything off which would add heat, start cold water into tank (also siphon). Window opened above tank for a few minutes and at subject request fan directed at face for cooling.

0445 Fan off subject, subject sleeping.

0500 Cold water stopped.

0510 Siphon stopped.

0520 Subject arouses temporarily to scratch back. He had mentioned earlier that back itched, but no irritation noted at that time. Might keep an eye on this area.

0533 Wiped oil off subject's face -- he inadvertently put hand on face while sleeping.

0545 Subject sleeping soundly.

0600 Started cleaning, etc.

0610 Subject now cooling -- t_r is 37.18° C.

0720 One underwater light on even though oil temperature is 34.7° C the t_r is dropping slowly into 36° C range.

0735 Light back off as t_r and oil temperature start back up.

Addendum: The reasons for subject removal of suit-helmet system 1) Too many adjustments to make to get comfortable enough to sleep, 2) ear pads become soft and don't hold rubber suit away from ears too well, and 3) air gets too hot coming in.

0800	Subject sleeping in sling. All quiet.
0900	Ditto. Occasional stirring in bath. Scratches head, ears, side.
0940	Moving more, eyes still closed. Arms folded. Asleep in sling.
1000	Subject awakens. Visitor here. To have breakfast and clean up. no rash.
1030	Cleaned up with sponge. New shorts. Had 120 ml. pineapple juice and one croissant (.05 lb).
1050	Ate 0.43 lbs. minestrone soup.
1100	Voided 230 ml. dark amber urine. Ran vacuum cleaner during voiding period to clean up any spillage. Subject cleaned area of bag around himself. Adjusted flow resistance of filter system to cool oil slightly (28 in 5 out).
1120	Subject in suit and submerged in bath. New ear pads.
1145	Comfortable position. Hips held down by weight belt, lens of faceplate just out of fluid. Neutral (no effort), Seeler valve is 5" below surface, at about level of sternal notch.
1200	Subject complained of a hum from the movie projector output. Grounded the projector which soon burned out the motor. Called for replacement
1210	Subject listening to tape recorder, appears to be comfortable.
1230	Bath temperature down to 31.5. Reset filter pressure to 20 in 10 out.
1235	Rectal still high. Open filter system up again. To 30.9 down.
1255	Lying quietly in same basic position and listening to tapes.
1300	Quiet.
1330	Movie again -- new projector.

Fourth Day

1400	End of third day. Subject sits up. Drank 120 ml. grape juice. Removed rubber suit and mask. Clean up time. PHisohex for hands and face.
1425	Drank 120 ml. lemonade.
1500	Lying back in oil with his suit and mask on.
1540	Watching a film.
1600	Bath temperature has dropped to 27.4° C. Making an attempt to raise it rapidly. All pumps on; hot water tank, etc.
1630	Shut down vacuum cleaner.
165	Subject submerged in suit. Listening to tapes.

1700 Resting quietly. Tapes

1800 Rectal temperature has been rising. despite his feeling cold 1 1/2 hours ago when out of suit and sitting. We were warming bag for a while, stopped about 1/2 hour ago.

1830 Discovered the t_O probe was under the subject -- was measuring water rather than bag temperature. Rectal still rising. Cooling actions initiated.

1850 Ears hurt. Out of rubber suit.

1900 Ate one hot dog. Drank 120 ml. grape juice.

1930 Rectal temperature still up -- passing 38° now. Decided to take him out to examine. Lying on edge. Ears clean, slight infection post. margin left tympanic membrane. ENT negative. Skin sore on left hand post. between 1st and 2nd metacarpal (which we thought was poison ivy before he entered the silicone fluid) has become solid, indurated deep red. Ring of dried papules in center. Similar (?) lesion starting on right hand Left leg on lat. aspect of calf shows 3 well-developed localized pustules in hair follicles. One more over right scapula, early one over left However - similar early lesions on front of both thighs (usually there) are gone. No papular rash. Skin generally looks fine. Smooth, clear, soft.

2015 Back into bath Rectal now reads 37.2 ! (it was out for 10 minutes.) We are checking out a new probe. Urine specimen of 1640 today examined by J. Annis shows the following: pH 7.0 - Sug., Neg.; Alb., tr.; 5-10 WBC (per hpf), rare RBC; phospate crystals; few bact.; oil drops.

2030 Rectal temperature is 38° C.

2035 Now 38 1° C -- subject chilling some. In oil - head in sling only.

2130 Lights, tank heater, vacuum pump on to warm bath as thermistor reads 25.6° C outlet. Subject rectal temperature remains near 38° C. Start to monitor temperatures at 15 minute intervals.

2150 Vacuum pump back on, was turned off at 2138, but bag started to cool once again. Response to pump on was almost immediate with a change in oil temperatures of 4° C in 2 minutes at thermistor in the Baker filter inlet. Suggest layering in fluid which is fairly pronounced. Thermometer at inlet read 33.6° C at about 5 inches under surface. Thermistor near inlet at bottom of fluid reads 33.3 to 33.4° C and at top 33.7 to 33.8° C.

2203 Vacuum cleaner off, temperature at head end is 32.1° C, after 5 minutes the temperature here had dropped to 28.5° C while the temperature at the foot end is fairly constant at 35.5° C. The main function of the vacuum therefore must be simply to propel the effluent (of both systems) through the bag faster so that the Δt (and time loss) in the

cycle is reduced and cooling is less. (fluid is clear, but slight odor still exists. Subject entertaining visitors and watching TV.)

2315 Visitors leave, subject urinates, scrubs off and drinks some grape juice. Some irritation noted on upper torso (slight papular rash on upper arm,shoulder and chest). Vacuun run during urination and scrubbing. Some cloudiness of fluid noted subsequent to period.

2345 Subject changed shorts, scrubbed and placed back in sling watching TV. Oil cooling and t_r coming down. Lights, heater back on.

2400 Scrub bag with renewed vacuum cleaner.

<u>4/7/66</u>

0140 Subject urinates 110 cc of amber urine.

0215 Ran about 3 minutes of hot water on top of pool to warm bag which feels cold on subject. Some improvement. Add foam circle which is placed under buttocks area to hold subject up away from bag.

0230 Start siphon to lower water level as subject angle is uncomfortable.

0300 Subject has been sleeping for approximately 30 minutes.

0400 Subject sleeping -- t_r reasonably steady.

0500 Add water to tank to raise level.

0530 Tank getting warm -- oil also.

0545 Subject arouses, adjusts sling strap.

0600 Subject resting -- sleep. Rash seems or appears to be somewhat improved.

0635 Subject sits up, warm in bag, sweating lightly. Start cold water to cool bath down. Wipe subject's face off.

0645 Subject drinks 150 ml. of lemonade.

0700 Subject goes to east end of bag.

0730 Subject sponges and scrubs west end of bag with vacuum. Treat spot on hand with alcohol-zephiran then pHisohex wash followed by alcohol-zephiran wash, and dry in air.

0745 Play tapes for subject. Metracal and orange juice.

0830 Pulse rate is 90/minute.

0835 Voided 250 ml. amber urine. Change shorts. Skin scrubbed with sponge.

0900 Sitting in bag with suit and mask on.

1000 Ate 3 pieces of bacon and drank 4 oz. of grape juice. (we are pushing fluids today to combat possible dehydration).

1110 Subject voided 250 ml straw colored urine.

1200 Resting on back in oil, watching film.

Fifth Day

1800 Running cold water into tank and siphoning out warm water. Water heater off, one light off Tank temperature at 29.9° C and rising.

1900 Subject in suit and submerged in bath. Visitors with him.

1930 Watching TV -- relaxed, submerged and floating.

2050 Subject sits crosswise in bag to talk with visitors -- t_r probe slips out once more.

2130 Subject urinates 430 cc amber urine.

2230 Last visitor leaves. Subject reclines to watch TV.

2330 Subject urinates

2345 Subject t_r temperature going up -- try cold water -- no complaint.

2400 Subject sits up in bag again to await removal of suit.

4/8/66

0020 Subject fitted to new sling, watches movie on TV (suit off).

0045 Subject changes trunks, scrubs, sweeps bag and changes rectal probes as original checked. Drinks 120 cc of lemonade.

0100–0130 Running hot and/or cold - hot alternately as per subject's wishes -- some chilling as t_r continues to rise. Hot water run around bag to warm as it feels cold against subject. Hope t_r will start to decline when subject gets to sleep. Subject, when quizzed, has no complaints.

0145 Subject asleep.

0200 Subject t_r starting to break, moving down.

0[illegible]5 Subject arouses in bag, scratches self, especially on back, and starts to remove trunks. When asked why he wants trunks off, answer that he wanted others on. When told that he had only had present pair on for an hour or so, he put them back on. Did not have to urinate, apparently only partly awake and thought it was morning. Returns to sling (new -- with rubber cushions,back strap) and goes back to sleep.

0312 Rectal probe acting up as subject is restless in sleep (back itches), thrashing around.

0450 Subject awakens, sits up out of sling, then lies bach with just head in both slings This arrangement doesn't look too secure, however cannot seem to arouse subject enough to get results to requests to return to original condition with slings. Start warm water in and siphon out to warm bath as subject does manage to say that he is cold. (Bath temp. 31°C at time). Also increase flow-output of Baker filtration equipment as it is fairly low.

0515 Subject returns to sling, continue to siphon, but no more hot water. Tank heater off. As bath warms can observe sweat beads form on back Apparently the moving and breaking loose of these beads is what causes subject to scratch Some evidence of irritation is now visible in area over manubrium.

0615 Subject urinates, sweeps bag with vacuum cleaner, bath too warm (as witnessed by his rising t_r) start to cool water.

0620 Subject back in harness to rest.

0710 Rectal probe going crazy again.

0850 Subject urinated 130 cc straw colored urine.

0900 Subject drank 2 oz. of orange juice. Asked for two aspirin table' and change of trunks.

0940 Into rubber suit and mask.

0940 Watching a film.

1020 Watching TV. Quiet. He has been touchy all morning. Is putting up with us and the experiment (just) because it is nearly over. We hope to keep him in suit until 1400.

1100 Lying quietly -- no TV, etc.

1300 Adding water to the tank to bring subject and bath level up for easier removal. Making final preparations.

1400 Out !! Feels fine.

Post Run Procedures

1420 Tilt test. Felt OK until about 5th minute, began sighing every 1/2 to 1 minute. At 7 1/2 minutes felt nauseous. Finished the 10 minutes at 70° tilt.

1430 Went to shower, felt weak. Noticed abdomen not tight -- guts seemed to fall and bulge lower portion of belly. Had hard time keeping balance on curved floor of shower. Urinated after sponging off. Had bowel movement. Finished shower. (150 ml of yellow urine.)

1500 Drew blood. Hematocrit 49 12 on both whole and oxalated blood. (as measured on Yellow Springs Instrument electronic hematocrit.)

1520 Electrodes on again. Ready for Balke test. Still weak. Balke went for 5 minutes (grade 4% during 5th minute). Pulse rate 140, went to 148 in first minute of recovery. Down to 90 in 3 minutes of recovery.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY *(Corporate author)* Aerospace Medical Research Department U.S. Naval Air Development Center Johnsville, Warminster, Pa.	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3 REPORT TITLE

Silicone Submersion - A Feasibility Study

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Phase Report

5 AUTHOR(S) *(Last name, first name, initial)*

Paul Webb, M.D. Webb Associates, Inc.
James F. Annis Yellow Springs, Ohio Contract Monitor: Randall M. Chambers

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
21 October 1966	53	5

8a. CONTRACT OR GRANT NO. N62269-3212 b. PROJECT NO. Air Task A34531 059 R02201 03 c. Problem Assignment J04AE13-7 and Work Unit MF 022.03.02.7002 Rept. No. 9 d.	9a. ORIGINATOR'S REPORT NUMBER(S) NADC-MR-6620 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this Document is Unlimited

11 SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13 ABSTRACT

This report details a study which demonstrated the feasibility of maintaining men totally and continuously submerged for five days by using silicone fluid in a specially designed tank. Five submersions were tried, 3 were in water for 6 hours for training purposes and 2 were in silicone; one for 16 hours and the final run which lasted a full five days (120 hours) with complete submersion for about 60% of the time and head out immersion for the remaining 40%. It was found that silicone fluid can be used as a weightless simulation medium in prolonged immersion and that subjects can be kept free of skin irritation or maceration for long periods of time if diligent quantity control of the fluid is maintained. It was also found that long submersion need not result in a negative water balance due to diuresis.

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
1. Silicone submersion						
2. Total body immersion						
3. Prolonged immersion						
4. Body waste disposition						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

DD FORM 1 JAN 64 1473 (BACK)

UNCLASSIFIED

Security Classification